A cohesive total ozone data set from the SBUV(/2) satellite system

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[1] The long-term data collection of total ozone estimates from the Solar Backscatter Ultraviolet Ozone Sensors (SBUV and SBUV/2) began with the launch of SBUV on NASA's Nimbus-7 spacecraft in 1978. Following this successful demonstration, the National Oceanic and Atmospheric Administration (NOAA) adopted the slightly modified SBUV/2 instruments for placement on the afternoon Polar-Orbiting Operational Environmental Satellites (POES). The SBUV/2 instruments have flown on NOAA-9, -11, -14, and -16 in the POES series, with NOAA-16 launched in late 2000. Three more instruments are scheduled for launches in the next 6 years. While the absolute calibrations of individual instruments are good, they give total ozone accuracies of approximately 2%. However, without further adjustment, such interinstrument differences pose significant problems for atmospheric ozone trend analysis. In this paper we use the differences between total ozone estimates from the instruments during periods with overlapping coverage to account for these possible calibration biases. We use the NOAA-9 SBUV/2 record as the reference standard because of the length of its record and the amount of overlap with other instruments' records. By applying adjustments to the other data sets based on these differences, a complete, unified data set is created for use in analysis of long-term changes. The monthly-averaged total ozone time series for 50°S to 50°N and the hemispheric subsets are compared to the results from two 2-D chemistry models as a demonstration of the usefulness of the unified data sets. *INDEX TERMS:* 0340 Atmospheric Composition and Structure: Middle atmosphere—composition and chemistry; 0394 Atmospheric Composition and Structure: Instruments and techniques; 1640 Global Change: Remote sensing; *KEYWORDS:* total ozone, total ozone trends, SBUV

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1. Introduction

[2] Since the late 1970s, there has been extensive interest in determining the trends or long-term variations in total column ozone to test theories of chemically induced ozone depletion [e.g., *Rowland and Molina*, 1975; *Crutzen*, 1973]. Estimates of trends have been based on either ground-based or satellite measurement systems [e.g., *World Meteorological Organization* (*WMO*), 1998; *Fioletov et al.*, 2002]. Researchers have shown that each system has its own strengths and weaknesses, but together contribute to the estimation and understanding of atmospheric ozone changes. The problem is difficult because an accuracy of better than 1%/decade is desired for estimates of the long-term trend. This often pushes the systems to their limits in terms of coverage, long-term calibration stability, and record continuity. Especially for satellite instruments, consistent merging of data from different instruments becomes a key problem.

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[3] In this paper, we examine the Version 6 algorithm total ozone estimates from measurements made by the SBUV instrument (on NASA Nimbus-7) and SBUV/2 instruments (on NOAA-9, -11, and -14 polar orbiting satellites), and we discuss and apply a methodology to develop a cohesive data set. We use the overlap between the instrument records to estimate their relative biases and adjust all the data sets to the NOAA-9 SBUV/2 as the standard. This forms a complete, unified data set for analysis of long-term changes or comparisons to long-term behavior predicted by numerical models. We do the latter with a comparison of the monthly-averaged total ozone time series for 50°S to 50°N and the hemispheric subsets to the results from two 2-D chemistry-transport models.

2. History and Issues of SBUV(/2) Instruments

[4] The original Backscatter Ultraviolet ozone sensor (BUV) was launched on board the NASA Nimbus-4 space-

craft in 1970, and was designed to provide estimates of both total ozone and the vertical distribution of ozone in the range of 25 to 55 km as described by *Dave and Mateer* [1967]. A description of the instrument was given by *Heath et al.* [1973]. This instrument operated well for the first two years, but the long-term calibration was uncertain and a partial failure of the spacecraft power system in 1972 led to severely reduced coverage in the later years. *Miller et al.* [1979] and *Stolarski et al.* [1997] note some of the BUV data limitations. The major problems encountered with the first instrument were resolved, and an improved instrument, the Solar Backscatter Ultraviolet ozone sensor (SBUV), was launched in late 1978 on board the Nimbus-7 spacecraft. It operated until 1990 producing almost 12 years of data (see *Bhartia et al.* [1995, 1996] and *Miller et al.* [1996] for history and description of the measurements and ozone estimates).

[5] With the success of the SBUV instrument, the National Oceanic and Atmospheric Administration (NOAA) selected this type of instrument to fly on the NOAA Polar-orbiting Operational Environmental Satellites (POES) series. The SBUV design was modified to include several improvements (e.g., an onboard mercury calibration lamp to track diffuser degradation), and the new instrument series was designated SBUV/2. Some of the calibration and operational behaviors of these instruments are discussed by *Ahmad et al.* [1994]. The POES series of satellites circle the earth with orbits passing near to the poles and fly with half of each orbit over sunlit portions of the earth and the other half over the night-side. Further, the POES satellites are placed in close to sun synchronous orbits, that is, over a period of time all of a given satellite's orbits will cross the equator on the dayside at nearly the same local time. (The drift in these equatorial crossing times is called orbital precession and will be discussed below.) Because they use backscattered solar radiation, the SBUV/2 instruments should ideally be placed on platforms with local equatorial crossing time close to noon. The POES satellites are classified by their equatorial crossing times and the direction of the orbital flight on the daylight-side crossing, that is, morning or afternoon and ascending (south to north) or descending (north to south). The SBUV/2 instruments have been placed on the following four afternoon ascending NOAA POES: NOAA-9, NOAA-11, NOAA-14, and NOAA-16. These satellites began their operation with local equatorial crossing times nominally at 2:00 PM. Three more SBUV/2 instruments are scheduled for launch on POES platforms in the next five years. The intent is to create a continuous satellite-measured record of both total columns and vertical profiles of atmospheric ozone from the start of SBUV in November 1978 until 2010 when the SBUV/2 is replaced by the next-generation operation ozone measurement system, the Ozone Mapping and Profiler Suite (OMPS) on the National Polar-orbiting Operation Environmental Satellite System (NPOESS), which is described at http://www.ipo.noaa.gov/images/OMPS_flyer.pdf.

[6] Two real-world factors have combined to complicate the SBUV(/2) data record. The first is that the NOAA POES instruments have maintained longer lifetimes than planned, allowing the launch dates of the next-in-series missions to be extended. The second is that the afternoon POES satellites were deliberately placed into orbits which precessed to later equatorial crossing times so that they would not drift closer to noon orbits where they would suffer from harmful shifts in the amounts of solar radiation falling on the cold side of the spacecraft platform. Thus, instead of a series of instruments on well-positioned (for backscatter measurements) platforms, the SBUV/2 instrument series has found itself on platforms with local equator crossing time getting later and later, resulting in viewing conditions with higher solar zenith angles (SZAs) where the ozone retrieval algorithm has poorer performance. The orbital drift can lead to the loss of coverage entirely at higher latitudes during parts of the year. For some of the platforms, changes in the orbit relative to the sun have placed the solar calibration system into shadow for over a year as the satellite changed from an ascending afternoon orbit to a descending morning orbit. With a gap in the calibration information, establishing the consistency between the afternoon and morning portions of the data sets becomes problematic. On the plus side, however, is the fact that, because the instruments have a tendency to be so long-lived, when the satellite continues its orbital precession it ultimately comes to a point such that the SBUV/2 can resume coverage on the descending portion of the orbit. For example, if the satellite began as a 2:00 PM equatorial ascending orbit, the SBUV/2 would make observations only during the ascending part of the orbit and the descending portion would be in darkness. As the satellite precessed to a 10:00 PM ascending orbit the ascending orbit would be in darkness, but the descending part of the orbit would cross the equator at about 10:00 AM and the SBUV/2 would be able to resume retrievals. For an example see the description of NOAA-9 SBUV/2 data record by *Planet et al.* [2001].

[7] In the situation described above, we are able to maintain coverage by switching between satellite systems that provide the best coverage at a given time. Of course, when we depend on instruments that are so long-lived we have a particular onus to maintain calibration of an optically based system. *Bhartia et al.* [1995] and *Ahmad et al.* [1994] describe some of the difficulties and solutions. Our ability to achieve this long-term stability within each system is depicted in Figure 1 which presents the monthly difference of SBUV(/2) minus Dobson at 23 sites worldwide from data archived at the World Ozone and Ultraviolet Data Center in Toronto, Canada (WOUDC). These are updated from the differences presented by *Planet et al.* [1994]. We see from this diagram that while there are obvious biases between instruments on the order of about 2%, the differences with time appear more stable. One period that appears to show an obvious variation with time is the later years of SBUV minus Dobson, February 1987 to June 1990, a period in which SBUV data had to be corrected for chopper synchronization errors. By 1988 the SBUV error had become significant relative to Dobson.

[8] The last point to be made is that, within this paper, we present results for the SBUV(/2) data derived from the Version 6 retrieval algorithm. This is the current operational algorithm used within NOAA and is described by *Bhartia et al.* [1996]. It also produces estimates of the vertical distribution of ozone. The Version 6 algorithm uses pairs of measurements, one at a wavelength with a large ozone absorption cross section and the other at a wavelength with a smaller cross section, to calculate the total column ozone estimates. Estimates can be created from different pairs to

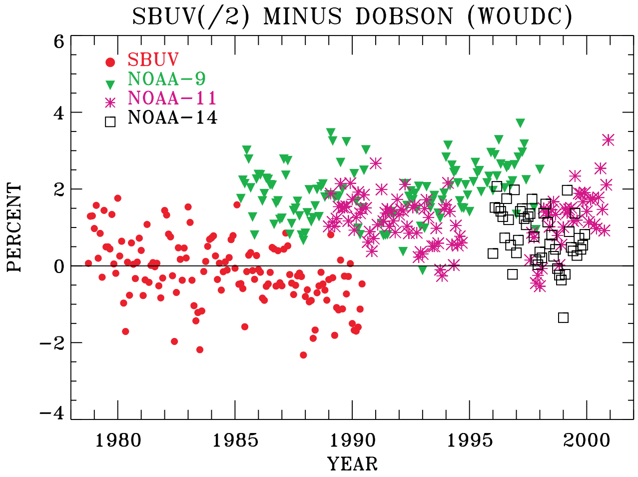

Figure 1. Monthly SBUV(/2) minus Dobson (%) at 23 World Ozone Ultraviolet Data Center sites.

check the internal consistency of the calibration. In particular, the 306 and 313 nm measurements have a very large difference in the ozone cross sections, making its ozone estimates (called the D-pair estimates) less sensitive to absolute calibration errors, and a small wavelength difference, making it less sensitive to wavelength-dependent calibration errors. Unfortunately, the large ozone cross section at 306 nm means that the measurements are sensitive to the ozone profile shapes, not just the total column ozone. To avoid large effects of the profile shapes, the D-pair is only computed for low total column ozone amounts and observation geometries with short path lengths. The path lengths for SBUV(/2) observations grow as 1+secant(SZA). In practice, D-pair retrievals are restricted to equatorial latitudes and SZAs less than 60° to satisfy this condition. Because of its inherent accuracy, D-pair total ozone values can be used as the basis for internal calibration of the spectral calibration of other ozone pairs. If the D-pair ozone results at the Equator are assumed to be correct, then we can require the ozone values derived from the other wavelength pairs to agree. The results of the use of the D-pair to obtain calibration for NOAA-9 SBUV/2 are presented by *Planet et al.* [2001].

[9] An important validation of the D-pair method was obtained by applying it to NOAA-11 SBUV/2 data between 1989–1994, where the onboard mercury lamp calibration system worked very well in establishing the changes in diffuser reflectivity [*Hilsenrath et al.*, 1995]. The performance of the onboard system was validated through comparisons with Space Shuttle SBUV (SSBUV) underflights. Thus, while we compare the final retrievals with the independent Dobson data, the long-term stability of each satellite's ozone data is determined solely by the information determined from the individual satellite.

3. Methodology

[10] As indicated in the work of *Weatherhead et al.* [1998], the detection of trends in a variable that undergoes a change in instrumentation is significantly enhanced if we have information that connects the two data sets, i.e. overlap, as opposed to having them disjoint. As seen in Figure 1, the former is the case for the SBUV(/2) data where we have significant overlap of data and we can compare the differences among the instrument records during the overlap periods to analyze the biases between instruments. Similar methods have been applied to time series data by *Christy and Lobl* [1998] and *Hollandsworth et al.* [1995]. The bias adjustment between two components is then applied to the entire record for one of them and the adjusted pieces are combined to develop a cohesive data set.

[11] This method requires that we select one instrument as the reference and adjust all other instruments relative to it. (Note that there is no implication that the reference is more accurate). For this paper we have opted to utilize the NOAA-9 SBUV/2 data as the standard. From Figure 1 we see that we have direct overlap of NOAA-9 with Nimbus-7, the first part of NOAA-11 (1989–1993) and NOAA-14. For the second part of NOAA-11 (1998–2000) we utilize the NOAA-9 to NOAA-14 differences and then the NOAA-14 to NOAA-11 differences to achieve a net adjustment of NOAA-11 to NOAA-9.

[12] Within Table 1, we give the period of data overlap and the maximum number of months used in the analysis. As described in Section II, when the SZA increases with changing equator crossing times, we tend to lose coverage in the higher latitudes. This, in turn, decreases the number of months of mutual data for the two systems during the overlap period. Typically the higher latitudes have about one-half of the number of months of overlap found in the tropics. Monthly zonal averages were computed for each instrument if there were 10 days or more of available data (with SZAs less than 80°) within the month. A reduced number of monthly matchups, of course, increase the standard error estimates of the mean difference. For the matchup procedure, we utilize monthly zonal average data over 10° latitude bands centered every 10° from 75°S to 75°N. One additional point should be noted. As described above, the NOAA-9 minus Nimbus-7 SBUV differences for the period January 1989 to June 1990 were not consistent with the differences for the period of March 1985 to December 1988. Comparison of the two periods indicated that the differences were largest at the mid-to-higher latitudes. Based on this and the results from Figure 1 we have limited our NOAA-9 minus Nimbus-7 overlap statistics to the period March 1985 to December 1987.

Table 1. Overlap Periods for SBUV(/2) Comparisons

Instruments	Period	Maximum Number of Points
NOAA-9 and Nimbus-7	March 1985 to December 1987	34
NOAA-9 and NOAA-11	January 1989 to October 1994	70
NOAA-9 and NOAA-14	January 1996 to July 1997	19
NOAA-14 and NOAA-11	July 1998 to December 2000	30

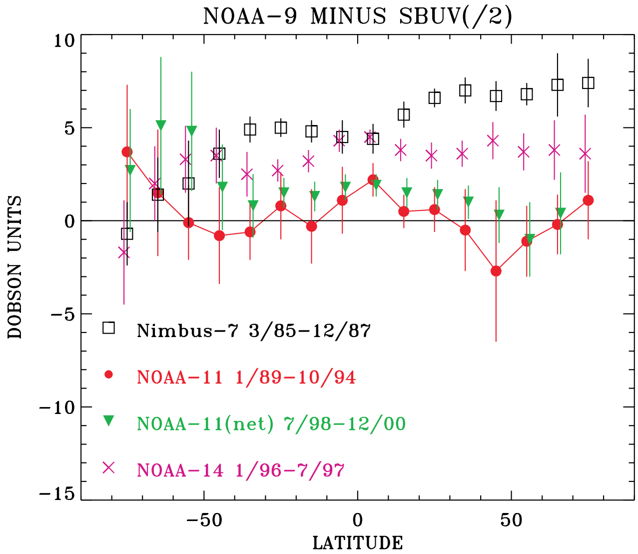

Figure 2. Average adjustments in Dobson Units to NOAA-9 as a function of latitude. Vertical bars represent 95% confidence limits.

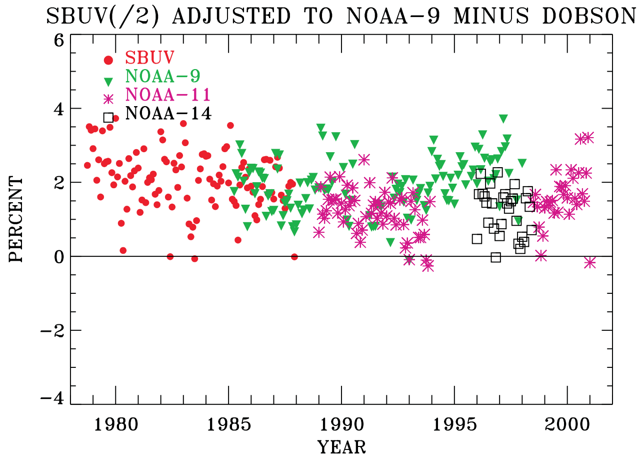

Figure 3. Same as Figure 1, but SBUV(/2) data have been normalized to NOAA-9.

[13] Within Figure 2 we present the computed adjustment from the comparisons in Dobson Units (DU). We have combined the data for NOAA-9,-14 and -11 to achieve a NOAA-9 minus NOAA-11 net value for the period July 1998 to December 2000. We see that for the Nimbus-7 comparisons, the differences have a hemispheric bias with the Northern Hemisphere higher by about 3 DU. This hemispheric bias is not as apparent in the other series except for some effects at the highest latitudes. As indicated above, there is a tendency for the number of matchups to decrease at the higher latitudes and this is indicated by the larger standard error estimates. One additional point that is worth mentioning is the observation that the differences between instruments appear to show a relatively sharp change in the high latitudes of the Southern Hemisphere. This raises the question whether this is a result of SZA effects, synoptic situation, the result of the decrease in the amount of data available at these latitudes for comparison or if there is some other cause. Unfortunately, the situation is quite complex as the comparisons are sometimes between ascending and descending satellite instruments and at other times descending and ascending, and the standard errors of the differences are relatively large. However, as this feature is not generally observed in the Northern Hemisphere, we believe this phenomenon to be a combined function of the SZA and the synoptic situation in the Southern Hemisphere. Finally, we note that the NOAA-11 comparisons for 1989 to 1994 are in general agreement with the results for the second period 1998 to 2000. When integrated over the domain 50°S to 50°N, the values of the biases for NOAA-11 versus NOAA-9 over the two periods differ by 0.3 DU.

[14] Within the comparisons we also examined the temporal variation of the differences between the instrument systems. For NOAA-9 minus Nimbus-7 and NOAA-11 (1989–1994), there is no apparent change with time. However, for NOAA-9 minus NOAA-14 the bias tends to increase by about 3 DU over the time period whereas the NOAA-9 minus NOAA-11 net (1998–2000) period has about a 3 DU decrease. Our adjustments only consider the average over the total joint period and thus may include a residual temporal difference.

4. Results

[15] The first question is how well have we succeeded in achieving a coherent database. We approach this in two ways. The first is through re-examining the SBUV/2 comparisons with the WOUDC Dobson data after adding in the SBUV/2 data normalization to NOAA-9. This is presented in Figure 3. We see that the impacts for both periods of NOAA-11 have been relatively minor, but that the results for NOAA-14 and Nimbus-7 have been made more consistent with NOAA-9. The average bias and standard deviation for each instrument and for the combined data are presented in Table 2. The results for NOAA-9 indicate that it is about 0.7% higher than NOAA-14 and the first section of NOAA-11, but only about 0.3% higher than the second section of NOAA-11. Overall, the average bias for the entire adjusted record versus the Dobson data is about 1.7% with a standard deviation of 0.7%. The biases for the individual data records range from 1.2 to 2.0%. Thus each section of the adjusted SBUV(/2) data record is now within 0.5% of the average Dobson difference for the composite data set.

[16] A second approach is to show the adjusted data with the overlaps as a function of time. For clarity of presentation, we show the results of the total ozone integrated over the domain 50°S to 50°N. This domain was selected because data are available for all except three of the months. For this data set, March 1991 and May 1993 are missing

Table 2. Adjusted SBUV/2 Minus Dobson Differences, in Percent

Satellite	Average Difference	Standard Deviation
Nimbus-7	2.0	0.8
NOAA-9	1.9	0.7
NOAA-11a	1.2	0.6
NOAA-11b	1.6	0.7
NOAA-14	1.2	0.6
Combined	1.7	0.7

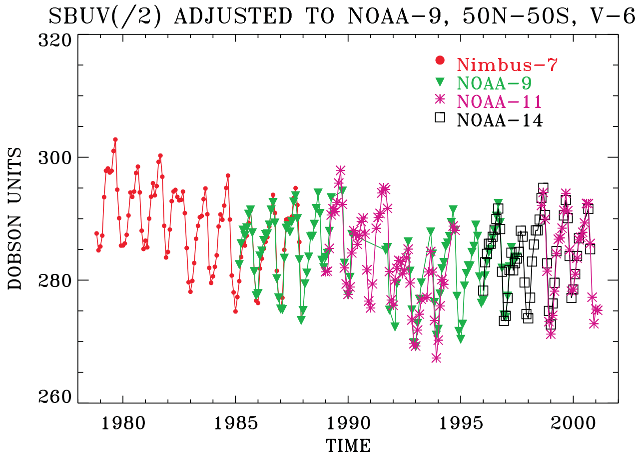

Figure 4. Monthly SBUV(/2) data adjusted to NOAA-9 and integrated 50°S to 50°N.

and June 1993 is not included as the data for the region 80°S to 40°S exceed the acceptable SZA criterion. As we extend the domain out to 60°S to 60°N then we begin to lose coverage due to increased SZAs as described in Section II. Within Figure 4 we present the monthly average values for each instrument for the area 50°S to 50°N adjusted to NOAA-9. Although the scale is somewhat compressed, the overall agreement between instruments is quite good and we see that the biases of one instrument-to-another have been essentially removed.

[17] For 50°S to 50°N another choice arises concerning the issue of data averaging. During the instrument overlap one option is to average the values of the two instruments. This would result in the "best" estimate for that month. However, this can lead to a situation where we have some months with two values and some months with one, again dependent on the SZA. Therefore we have decided not to average the data in the overlap periods, but rather to append one satellite's data record to the others depending on best overall coverage. The time periods used are presented in Table 3. Notice that we migrate between systems based on the coverage. As noted above, for the area 50°S to 50°N, we are missing only three of the months; March 1991 and May and June, 1993.

[18] When we combine the data in the above manner, we arrive at the time series depicted in Figure 5. The time series shows a general decrease from 1979 with the lowest values in the Northern Hemisphere winter of 1992/1993 associated with the aerosols from the eruption of Mt. Pinatubo and the chemical loss in the lower stratosphere attributed to heterogeneous chemistry [*Schoeberl et al.*, 1993; *Gleason et al.*, 1993; *Solomon et al.*, 1998]. Thereafter, a general increase or at least a leveling-off is observed.

[19] While an annual cycle is evident in the data of Figure 5, it does not account for all of the variability and, therefore, we have chosen to average the data by year to compare against the results from 2-D models. These results are depicted within Figure 6. For comparison purposes, we have plotted each data set as the percent change in total ozone since 1979. The filled circles are the data from the SBUV(/2); and the solid line is from the Goddard Space Flight Center (GSFC) 2-D model which was used to

Table 3. Periods of Use for Individual SBUV(/2) Instruments in the Combined Total Ozone Data Record

Satellite	Start	End
Nimbus-7	November 1978	February 1985
NOAA-9	March 1985	December 1988
NOAA-11	January 1989	December 1993
NOAA-9	January 1994	December 1995
NOAA-14	January 1996	July 1998
NOAA-11	August 1998	December 2000

simulate the past and future ozone changes. The GSFC 2-D model included the effects of anthropogenic chlorofluorocarbons and halons, solar cycle ultraviolet flux variations, the changing sulfate aerosol abundance due to several volcanic eruptions including the major eruptions of El Chichon and Mt. Pinatubo, solar proton events, and galactic cosmic rays for the time period 1979 through 1994 as described by *Jackman et al.* [1996]. The boundary conditions for source gases (including halons and chlorofluorocarbons) in the period 1995 through 2050 were taken from scenario A/A3 given by *WMO* [1998]. The solar cycle ultraviolet flux driven variations for 1995 through 2050 were idealized assuming an amplitude of 1.2% in yearly average total ozone change from solar maximum to solar minimum following a sinusoidal variation with assumed solar maxima in 2002, 2013, 2024, 2035, and 2046. For the 1995 through 2050 time period, the sulfate aerosol densities were seasonally fixed using the 1995 data from SAGE II and no solar proton events or galactic cosmic rays were included. The dashed line is based on results from the University of Illinois 2-D chemical-transport model of the global atmosphere (UI 2-D). Recent publications that describe the model include *Wuebbles et al.* [1998, 2001], *Kotamarthi et al.* [1999] and *Wei et al.* [2001]. The changes in ozone with time are evaluated in the model for a scenario very similar to that used in the GSFC studies. These include the effects of changes in emissions of CFCs, halons, and other halocarbons, changes in surface emissions for methane, nitrous oxide, and other gases, changes in the solar flux, and changes in the sulfate aerosol loading from the volcanic eruptions.

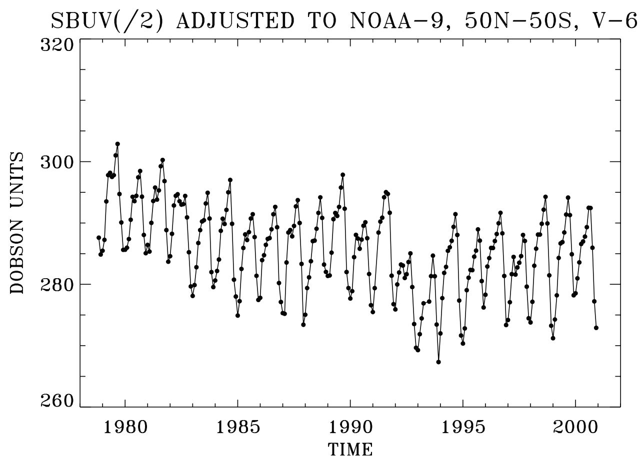

Figure 5. Time series of monthly SBUV(/2) data adjusted to NOAA-9 and integrated over 50°S to 50°N.

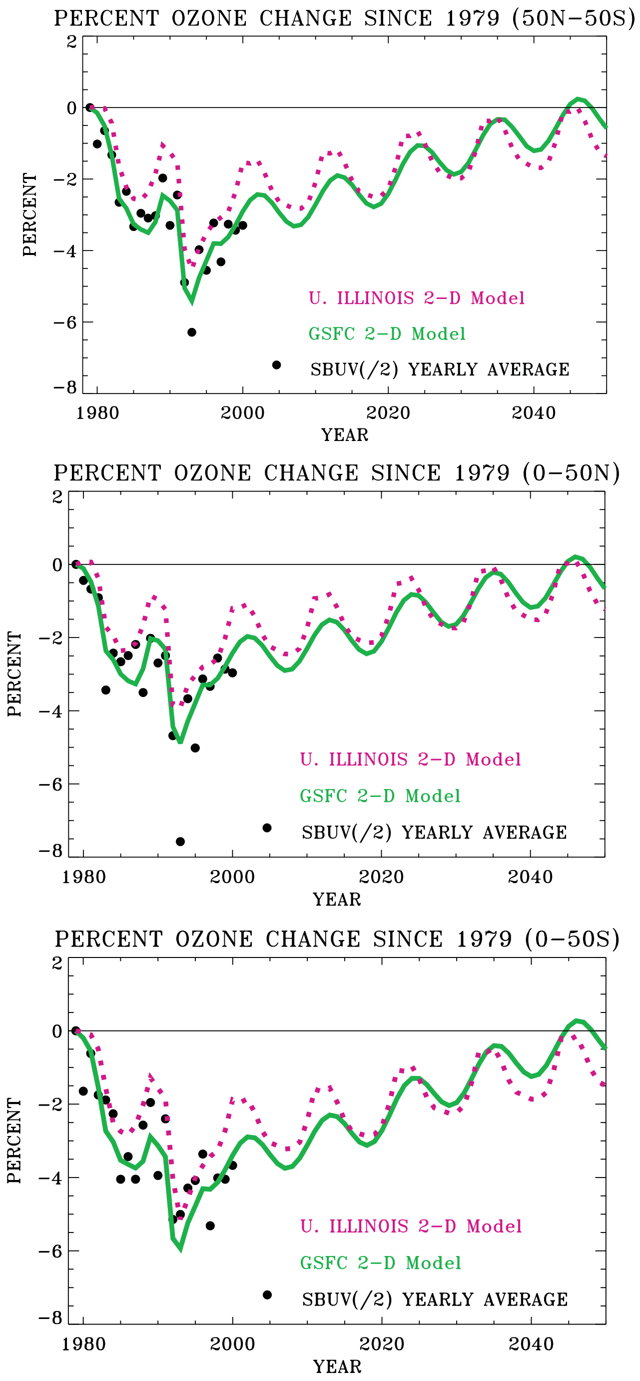

Figure 6. Ozone change since 1979 (in %) computed from adjusted SBUV(/2) (solid points) and from two 2-D models (see text for references). Area for 50°S to 50°N (top), Equator to 50°N (middle), Equator to 50°S (bottom).

[20] Within Figure 6 we depict the results for the area 50°S to 50°N (top) and we see that the general agreement between both 2-D models and the data is extremely good and each captures the essence of the decrease from 1979 and the increase since 1993. In addition, both models include terms to model effects of the 11-year solar cycle, which appear to be in agreement with the data. The large area average, however, can mask individual hemispheric events and within Figure 6, middle and bottom we depict the results for Equator to 50°N and Equator to 50°S, respectively. For these areas we see that the issues are not as straightforward. For the Northern Hemisphere the agreement is generally quite good except for 1993 when the observations are about 3 to 4% lower than the models. This is believed to be due to the effects of the aerosols associated with the Mt. Pinatubo eruption along with the fact that the current models do not include temperature fluctuations [*Solomon et al.*, 1998]. This statement must, however, be tempered somewhat by the fact that in 1993 the months of May and June are missing from the SBUV/2 record and the average is based on only the available 10 months. For the Southern Hemisphere, the Pinatubo eruption does not appear to have the same general impact and the agreement with the models is generally within approximately 1 to 2%. For all three areas the UI 2-D model indicates a somewhat higher relative maximum than the GSFC 2-D model and recovers a bit faster from the early 1990s minimum.

[21] One final thought on the interpretation of the data. To this point, the emphasis on ozone change detection has focused on using a "hockey stick" with no trend prior to 1970 and a linear trend since 1970. This was based on the science community's best estimates of ozone change at the time [e.g., *WMO*, 1998; *Reinsel et al.*, 1994]. The results of this paper and the comparisons with current 2-D models indicate that we need to reinterpret the ozone changes and model them in a more sophisticated manner in statistical time series analyses. In addition, as indicated, for example, by *Fusco and Salby* [1999], *Randel and Cobb* [1994], *Finger et al.* [1995] and *McCormack et al.* [1998] the role of low frequency variability in the tropospheric-stratospheric interaction needs to be considered in the depiction of ozone change.

5. Summary

[22] Through use of the overlap periods of the various SBUV(/2) total ozone data sets, we have been able to create a cohesive and essentially continuous data set from November 1978 through December 2000 for the region 50N–50S, even though 3 months are missing. As we restrict the data to solar zenith angles less than 80°, if we were to extend the analysis to more poleward latitudes more months would be deleted. In the end, the question is how successful have we been and how do we compare with ground-based and other satellite data. As we have shown, after adjustment to NOAA-9, the composite data set comparisons with the Dobson data indicate an overall bias of about 1.7% and a standard deviation of about 0.7% with each instruments subset within 0.5% of the average. In addition, *Fioletov et al.* [2002] have compared the SBUV(/2) data against the ground-based data, several versions of the TOMS ozone data set (including the merged satellite data) and the NIWA assimilated data (TOMS and GOME data adjusted to match ground-based observations. Their results indicate that the SBUV(/2) cohesive data are generally within about 0.5% of the average of all the data with the exception of the periods 1989 to 1993 and 1999 when the differences increase to about 1% with SBUV(/2) being lower than the others. The former period is a part of the first NOAA-11 period and the result is larger than our Dobson comparisons suggest.

The differences for 1999 are imbedded within the overall second period of NOAA-11 so this result reflects the general limit of our calibration ability to determine the total ozone.

[23] Comparison of the data with the 2-D models from Goddard Space Flight Center and the U. Illinois indicates a general agreement in the variation with time and are generally within 1% of the SBUV(/2) data. The most obvious difference is in 1993 when the data are several percent lower than the models. When the comparisons are divided by hemisphere, we see that the Northern Hemisphere agreement is generally quite good again save for 1993 when the observations are about 3 to 4% lower than the models. This is believed to be due to the effects of the aerosols associated with the Mt. Pinatubo eruption along with the fact that the current models do not include temperature fluctuations, which can impact the chemical depletion impact [*Solomon et al.*, 1998]. The statement on model agreement, however, must be tempered somewhat by the fact that in 1993 the months of May and June are missing from the SBUV/2 record and the average is based on only the available 10 months. For the Southern Hemisphere, the Pinatubo eruption does not appear to have the same general impact and the agreement with the models is generally within about 1 to 2%. For all three areas the U. Illinois model indicates a somewhat higher relative maximum than the GSFC model and recovers a bit faster from the early 1990s minimum.

[24] The zonal average data from 80°S to 80°N in 10° latitude increments are available at the NCEP anonymous ftp site, ftp.ncep.noaa.gov, in the ASCII data file/pub/cpc/nagatani/sbuv2.dat. Alternatively, one can access the site via the World Wide Web by using ftp://ftp.ncep.noaa.gov/pub/cpc/nagatani, and clicking on the sbuv2.dat link. One can obtain the monthly product master files for SBUV/2 data from the NESDIS anonymous ftp site, orbit-net.nesdis.-noaa.gov, in subdirectories of /pub/crad2/.

[25] Finally, we should mention the possibility of extending analysis of this type to the SBUV(/2) ozone profile data. At this time we have compared the SBUV/2 vertical ozone profile data against that of SAGE II and our analysis indicates that significant variations in time occur within each SBUV/2 period. This precludes doing a simple overlap analysis and we are examining alternative mechanisms to achieve a coherent ozone profile data set.

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